

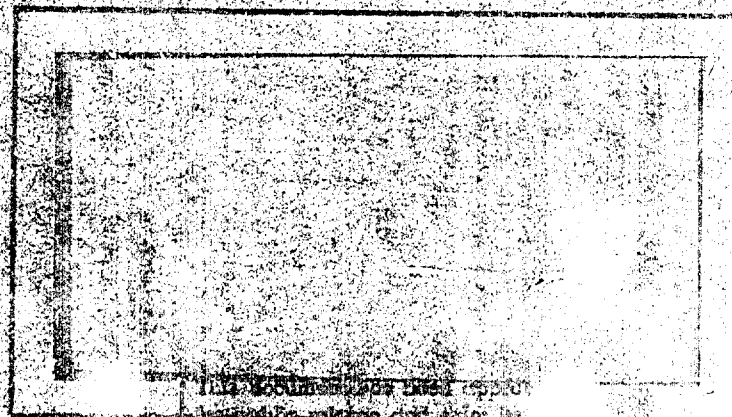
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AN EXPERIMENTAL STUDY OF A
CATALYTIC COMBUSTOR
FOR AN EXPENDABLE TURBOJET ENGINE.

THESIS

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AN EXPERIMENTAL STUDY OF A
CATALYTIC COMBUSTOR
FOR AN EXPENDABLE TURBOJET ENGINE

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by

Larry E. Taylor, B.S.

1 Lt

USAF

Graduate Aeronautical Engineering

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Preface

Six previous theses at the Air Force Institute of Technology (AFIT) have investigated the concept of producing a small, low cost, expendable turbojet engine for remotely piloted vehicles (RPV's). These engines were derived from automotive and diesel engine turbochargers to which inlets, combustors, and exhaust nozzles were added.

This work was a continuation of a study that used a catalytic combustor with hydrogen fuel. A second hydrogen fueled catalytic combustor was designed and tested which proved successful over wide operating ranges.

I would like to thank the following for their assistance:

Dr. William Elrod, thesis advisor, for his ideas and support.

Dr. Harold Wright and Capt. Richard Merz, AFIT professors, for their constructive remarks.

Mr. Dave Wilkinson, Air Force Aero Propulsion Laboratory, for sponsorship and suggestions.

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Lieutenants Mike O'Brien and Bob Barham, fellow students, for their time during the many hours of calibration and testing.

Finally, I would like to thank my wife, June, for her patience, understanding, and support.

Larry E. Taylor

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List of Symbols

| <u>Symbol</u> | <u>Quantity</u> | <u>Units</u> |
|---------------|-----------------------------|--------------|
| h | fuel flow manometer reading | in. water |
| \dot{m} | mass flow | lbm/sec |
| P | pressure | psi |
| T | temperature | degrees F |

Subscripts

| | | |
|-------|--------------------------|---------|
| a | ambient conditions | |
| ac | air flow corrected value | lbm/sec |
| am | air flow measured value | lbm/sec |
| c | corrected value | |
| g | gage value | |
| H_2 | hydrogen value | |
| loss | total pressure loss | |

Engine Stations

| | |
|---|------------------|
| 3 | combustor inlet |
| d | combustor dome |
| 4 | combustor outlet |

Abstract

A catalytic combustor was designed, an existing one modified, and both were tested on a small turbojet engine. The turbojet engine was derived from an automotive turbo-charger for use on remotely piloted vehicles. The existing catalytic combustor, combustor "A", used straight through flow and was modified by adding a flame arrestor to the combustor inlet. Combustor "B" was designed to use reverse flow with a preburner and air dilution zones.

Combustors "A" and "B" were designed for an air capacity up to 0.75 lbm/sec and outlet temperatures of 1800 F. Combustor "B" did prove successful. Cold flow total pressure loss in combustor "B" was two percent, while the total pressure loss during heat addition was a maximum of seven percent. The flame arrestors tested on combustor "A" did not prove to be successful. Hydrogen was used as fuel for both combustors.

Temperature surveys were performed on combustor "B" in front of the catalytic element and at the turbine inlet. Temperatures across the catalyst face varied by 290 F at a turbine inlet temperature of 1070 F, 370 F at 1450 F. Turbine inlet temperatures varied by 55 F at an average 1045 F, 190 F at an average 1475 F. The maximum temperature rise across the combustor during testing was 1565 F and the maximum turbine inlet temperature tested was 1855 F.

AN EXPERIMENTAL STUDY OF A
CATALYTIC COMBUSTOR
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I. Introduction

Background

During the past few years the Department of Defense has placed increased emphasis on remotely piloted vehicles (RPV's). One of the major reasons is the relative low cost as compared to manned vehicles. Towards this purpose the Air Force Aero Propulsion Laboratory has been investigating the feasibility of small, low cost, expendable turbojet engines for RPV's derived from mass produced automotive and diesel engine turbo/super-chargers.

Six recently completed AFIT theses were sponsored by the Aero Propulsion Laboratory for this reason. Greene (Ref 4) and Kent (Ref 5) performed the initial studies by developing and testing two small turbojet engines that used JP-4 fueled combustors. The smaller engine used the Rajay 370E automotive turbocharger and the larger an AiResearch T18A-E diesel turbocharger. Fisher (Ref 3) improved the test facilities by enabling remote control testing of the engines and simultaneous recording of major engine parameters and increased instrumentation. This allowed Brown (Ref 1) to perform an enhanced experimental study of the larger engine along with his computer modeling study. Later an afterburning configuration of the larger engine was tested

by Wolfe (Ref 8), which achieved a maximum thrust of 114 lbs.

During Greene and Kent's initial testing, however, the small engine was mainly used for proof of the turbocharger engine concept. The combustor functioned on the engine but it had a very wide scatter of turbine inlet temperatures (400 - 1800 F at an average of 1565 F, Ref 4:19). Durniak (Ref 2) attempted to improve engine performance with several combustor designs, including a catalytic combustor using hydrogen for fuel. The catalytic combustor worked on the small engine, but difficulty was encountered in controlling the combustion reaction; the combustion flame would propagate upstream to the injection point in the inlet pipe.

Catalytic Combustors

Most modern automobiles have catalytic converters in their exhaust systems for oxidizing unburned hydrocarbons, carbon monoxide, etc., to produce a cleaner exhaust. A catalytic combustor works in much the same manner, but the total combustion process takes place in a catalytic combustor - from unburned reactants to reacted products. (See Ref 7 for a more detailed discussion.)

The catalytic element usually is made of a ceramic honeycomb matrix structure with square or circular holes which extend throughout the length of the element. Platinum and palladium are deposited on the exposed surfaces usually in a 2:1 ratio for automobiles. Other noble metals are sometimes used, in varying ratio and loading (amount of catalyst per area) configurations (Ref 7).

Catalytic combustors can offer several advantages over normal combustors. Higher average turbine inlet temperatures (resulting in decreased size, increased thrust, and decreased thrust specific fuel consumption) can be sustained due to a more uniform turbine inlet temperature profile. Enhanced operational stability can also be achieved for two reasons. First, catalytic combustors can operate outside the normal fuel/air ratios of standard combustors. Mixtures can be very lean or rich and combustion will still occur. Secondly, the thermal inertia of the ceramic bed is much larger than that of a conventional combustor (due to the heat storage ability of the ceramic bed), thereby damping the temperature fluctuations caused by turbulent mixing and uneven fuel/air distributions in the combustor (Ref 7).

The major disadvantages of catalytic combustors are their temperature limitations and susceptibility to vibrations or shock loads (resulting in cracking). Catalytic elements made of cordierite are limited to temperatures below 2200 F, therefore good mixing and atomization (liquid fuels only) are required in the inlet to the catalytic element to avoid any local "hot spots". Silicon carbide catalytic elements can operate at temperatures up to 3000 F, but are five times more expensive (Ref 7, Ref 2).

Flame Propagation Speed

The speed of a propagating combustion flame depends on many variables. The temperature and pressure of the reactants

and the amount of turbulence present are only three of these variables (others will not be discussed here). Of these three, the hardest one to measure and control is turbulence. Turbulent flame speeds are much higher than laminar ones and very hard to predict accurately. The flame propagation speed of the hydrogen fueled turbocharger engine with combustor "A" was estimated to be 200 - 300 ft/sec.

Flame propagation (of premixed fuel/air mixtures) into a given area upstream of a burning mixture can be prevented if the velocity of the fuel/air mixture is greater than the flame speed. This can be accomplished in subsonic flows by imposing an area restriction in which the velocity is increased. When the velocity of the fuel/air mixture through the area restriction is greater than the turbulent flame speed of combustion taking place downstream, the flame will not propagate through the area restriction flame arrestor.

Objective

The objectives of this investigation were to:

1. Develop a flame arrestor to prevent flame propagation into the inlet pipe on combustor "A".
2. Design, test, and evaluate a lower heat loss, reverse flow catalytic combustor, combustor "B", on the Rajay 370E turbocharger engine.

Scope

The initial investigation will be limited to the testing of five flame arrestors on combustor "A". Combustor "B" will

be developed using the results of this initial investigation.

Testing will be performed on an external air supply test stand for preliminary results and modifications. After modifications, the combustors will be tested on the Pajay turbocharger engine. Combustor performance and compatibility with the engine will be investigated.

All engine testing will be limited to static testing. No attempt will be made to produce light weight configurations for actual flight applications.

II. Description of the Combustors

Combustor "A" and "B" are catalytic combustors which use hydrogen for fuel. Both combustors were designed to be used with the Rajay turbocharger in order to produce a small turbojet engine for an expendable RPV.

Combustor "A"

Combustor "A" was a modified catalytic converter originally built for a Ford truck (Fig 1 and 2). The catalytic element, which is made of cordierite with square holes, has a noble metal loading of platinum/palladium in a 2:1 ratio. A flame arrestor was added at the combustor inlet to improve control of the combustion reaction.

Hydrogen fuel injection was in the inlet pipe approximately 10 in. upstream of the flame arrestor to provide an adequate distance for fuel/air mixing. The injector was located at the centerline of the inlet pipe and injected hydrogen into the downstream flow with a five hole arrangement.

Five flame arrestors were fabricated which would provide flow velocities of 100 to 400 ft/sec through their air passages. All five were made from one-sixteenth inch thick stainless steel. Two flame arrestors were made using a small number of large holes while the remaining three used a large number of very small holes. Hole sizes ranged from 0.038 in. (for 400 ft/sec) to 0.625 in. (for 100 ft/sec), with only one size of holes being used in each flame arrestor.



Figure 1. Combustor "A" and Engine

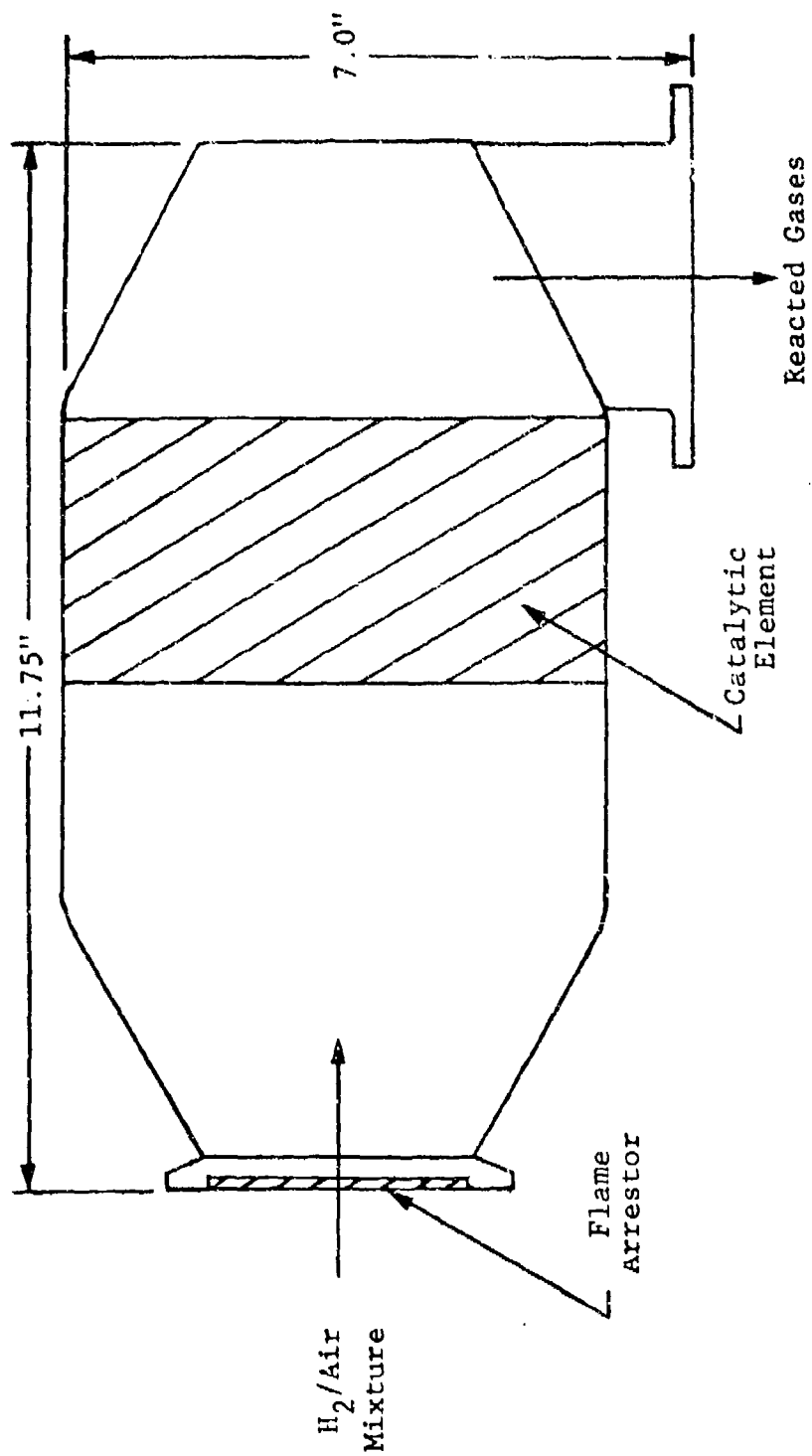


Figure 2. General Dimensions of Combustor "A"



Figure 3. Combustor "B" and Engine

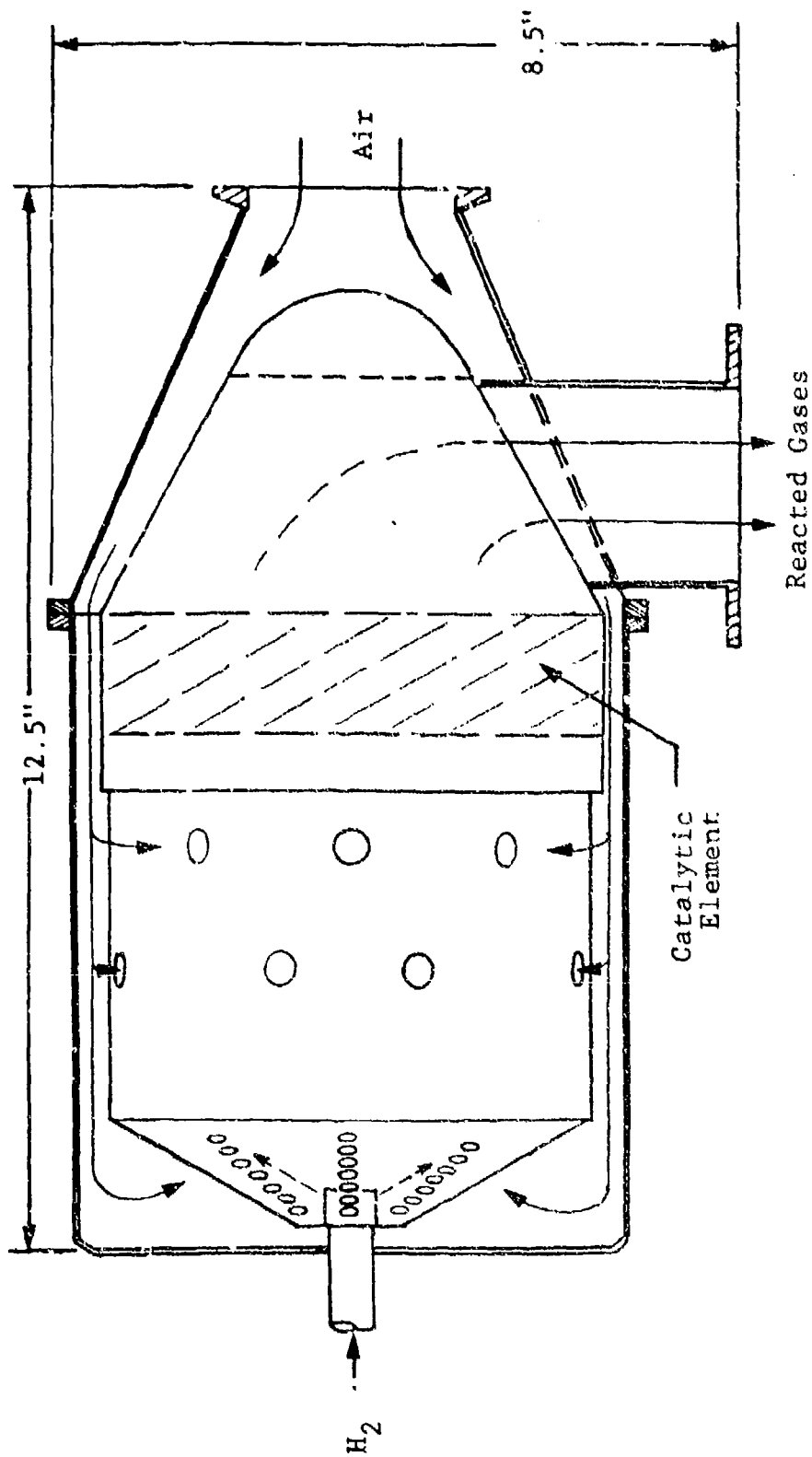


Figure 4. General Dimensions of Combustor "B"

Combustor "B"

Combustor "B", shown in Fig 3 and 4, is a reverse flow catalytic combustor that uses a preburner and air dilution zones. It was designed for 50% air flow through the combustor dome and 50% through the dilution air ports.

The combustor dome has 64 air inlet holes and 8 swirler vanes on the inside of the dome. Sixteen air dilution ports are staggered around the liner in two 8 hole rows. Hydrogen was injected into the dome by a fuel line that entered through the outer liner. Three injectors were investigated, two with 8 holes and one with 16 holes. Fuel line pressure for injection varied with the different injectors. For the small 8 hole injector the pressure was 0 - 220 psig; the larger holed 8 hole injector required 0 - 150 psig; the 16 hole injector required 0 - 80 psig.

III. Test Apparatus

Control System

The test facility layout is shown in Fig 5. Control of the combustor testing (on the turbocharger engine) was from the control room. All gases used in testing were located outside of the building and gaseous flow rates were regulated by nitrogen pressurized dome valves. Several electric and manual open/close valves and one-way check valves are also located within the system for complete control.

Compressed air was supplied by an MA-1A air cart during bench testing and was disconnected during turbocharger engine testing. In normal and emergency shutdowns, hydrogen flow to the combustor was stopped and followed by nitrogen purge gas which also purged all indoor fuel lines of hydrogen.

External Air Supply Test Stand

Both combustors "A" and "B" were designed to be used on the Rajay turbocharger/turbojet engine. Bench testing, however, used an external air supply to simulate the compressor output of the engine.

Figure 6 presents the external air supply test configuration. An MA-1A air cart (used for aircraft jet engine starting) supplied compressed air to the test stand. The amount of air supplied was regulated by a three inch gate valve upstream of the plenum. The plenum was used to dampen any flow oscillations into the combustors and to measure the

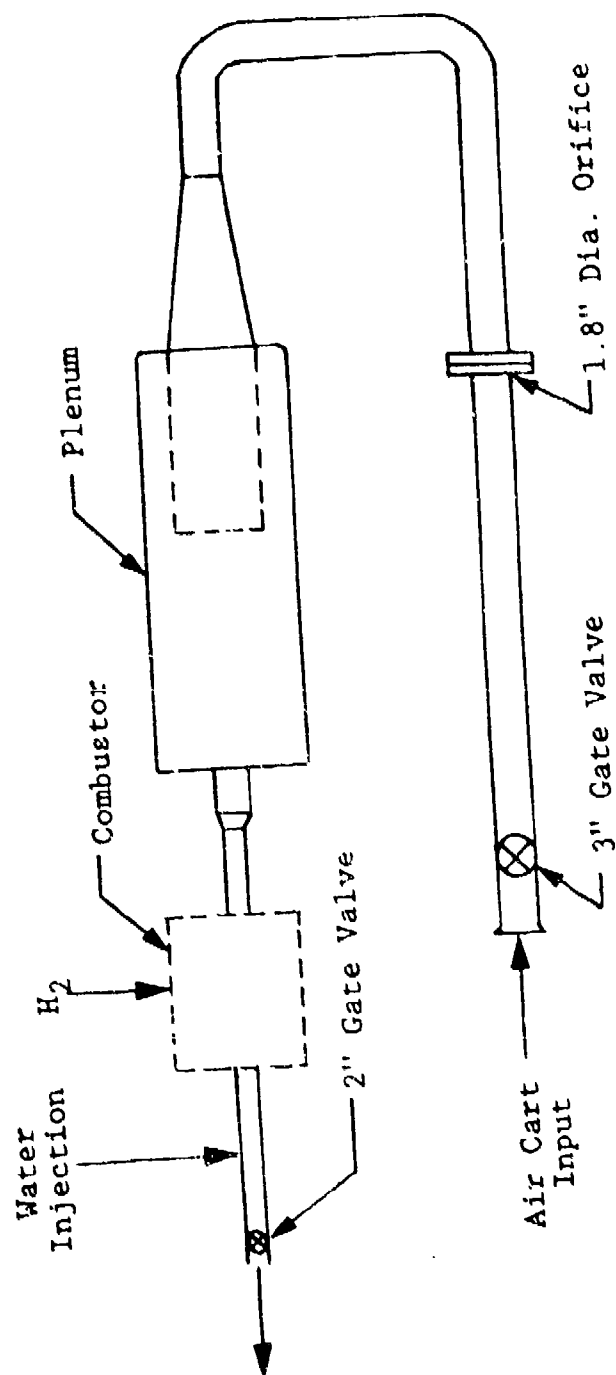


Figure 6. Schematic of External Air Supply Test Stand

total temperature and pressure of the supply air. Air mass flow was measured by static taps on either side of the 1.8 in. diameter orifice connected to a mercury manometer. A two inch gate valve controlled the back pressure on the combustor. To protect the valve, water injection was added between the combustor outlet and the gate valve.

Two 2.5 in. outside diameter stainless steel inlet pipes were used during testing on combustor "A". The short (18 in.) inlet pipe was designed to be used on the engine for combustor "A". A longer (5 ft), relatively straight inlet pipe was tested to allow better mixing of the hydrogen and air and to prevent any possible recirculation regions. For combustor "B" a flexible hose was used as an air inlet.

Simulated engine operation points were obtained by adjusting the two gate valves and hydrogen fuel flow to obtain the desired inlet mass flow at the correct inlet pressure for a given combustor exit temperature.

Turbocharger Engine Test Stand

The main components of the turbocharger engine were the Rajay 370E turbocharger, bellmouth inlet, exhaust nozzle, and combustor "A" or "B" (see Fig 1 and 3).

The engine was started using an impinging air jet on the turbine wheel to provide a sufficient compressor mass flow for the introduction of fuel. Once engine idle conditions were obtained, the air jet was shut off. Lubrication oil was supplied to the turbocharger bearings by a 28 VDC electric motor from a five quart capacity oil reservoir

located below the engine.

Four turbine housings were available with the Rajay turbocharger, these differing from each other by their aspect ratio (Fig 7). All four ($A/R = 1.0, 0.9, 0.8, 0.7$) were tested on the engine with five exhaust nozzle combinations. The exhaust nozzle exit diameters ranged from 1.75 in. to 2.50 in. in quarter-inch increments with the fifth being no nozzle at all (2.75 in.).

Complete engine control (unlike the external air supply test stand) was available at the control panel. Once a given turbine housing and nozzle were installed, the only controlled variable was fuel input, thus allowing the engine to seek its own operation condition with this housing/nozzle combination.

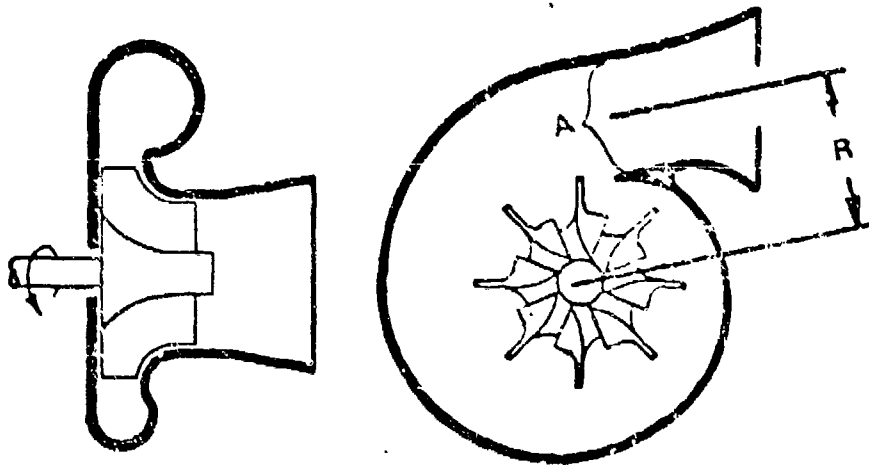


Figure 7. Turbine Housing Aspect Ratio

IV. Experimental Results

By testing catalytic combustors "A" and "B" on an external air supply test stand and the Rajay turbocharger engine, the following results have been obtained.

Combustor "A"

Initial testing of combustor "A" was on the external air supply test stand (bench testing). Of the five flame arrestors tested, four prevented flame propagation into the long inlet pipe. Flame propagation was determined by monitoring a chromel-alumel thermocouple placed 2 in. upstream of the flame arrestor. The flame arrestor with the largest air passages (lowest velocity) allowed flame propagation upstream and testing was discontinued on this flame arrestor. The two flame arrestors with the smallest air passages (highest velocities) showed no signs of upstream flame propagation at combustor exit temperatures up to 1900 F. The two intermediate ones had a transitory operation region between 1000 - 1200 F where intermittent flame propagation was noticed but was not serious enough to stop testing. After this transitory region was passed no flame propagation occurred up to the maximum temperature of 1900 F. With the short, curved inlet pipe, the three flame arrestors with the highest velocities prevented flame propagation with the largest of the three (largest air passage area) exhibiting the same transition region.

When these three flame arrestors were tested on the

engine, however, all three allowed flame propagation through the flame arrestor. The two with the smallest air passage areas caused back pressures to the compressor such that very little air flowed through the compressor and combustor. The engine starting system was operated with maximum air jet impingement on the turbine wheel and hydrogen flow was introduced slowly in an effort to increase engine speed and therefore increase mass flow. This did not work on either of the two; the flame propagated through the arrestor before the engine could be started. This was due to the fuel/air ratio becoming high enough for free (noncatalytic) combustion while the air mass flow was very low, therefore the velocity through the arrestor was lower than designed at these conditions. The engine was started with the intermediate size flame arrestor, but propagation occurred at 1400 F due to the same factors as for the two smaller arrestors.

Combustor "B"

Experience with flame propagating upstream of the catalytic element in combustor "A" suggested the provision of a flame holding and combustion region ahead of the catalytic element. The catalyst in this design serves as an ignitor and to insure complete combustion of a well mixed combustible prior to entering the turbine. Combustor "B" was designed with a combustor dome so a region of controlled fuel/air mixing and burning could occur.

Bench testing of this combustor resulted in catalytic element failure due to inadequate mixing of the fuel and air.

Dilution ports were added which greatly enhanced mixing and also decreased the velocity in the combustion zone between the dome and dilution ports, thus increasing stability. No catalytic element damage occurred when the modified (dilution ports) combustor "B" was bench tested up to 1800 F turbine inlet temperature.

Temperature Surveys. For the reasons just described, only combustor "B" was tested on the engine with the various turbine housing/nozzle combinations. Since turbine inlet temperatures are usually very uniform in a catalytic combustor, the critical factor is the catalytic element inlet temperatures. Figure 8 presents the results of temperature surveys across combustor "B" at a line (on a diameter) 0.5 in. in front of the catalyst face. In Fig 8A, temperature variations of 380 F across the combustor were about the same for the two 8 hole injectors, though the fluctuations are smaller for the smaller holes injector, showing it to have a better mixing effect. Figure 8B shows the results from catalyst face surveys at two turbine inlet temperatures with the 16 hole injector. At the lower temperature, this injector provided a lower maximum temperature scatter (290 F) than either 8 hole injector and therefore was used for the rest of the testing.

As the turbine inlet temperature was increased the temperatures varied more widely at the catalyst face (on an absolute basis), showing less uniform mixing. The temperatures varied from low on one side to high on the other due

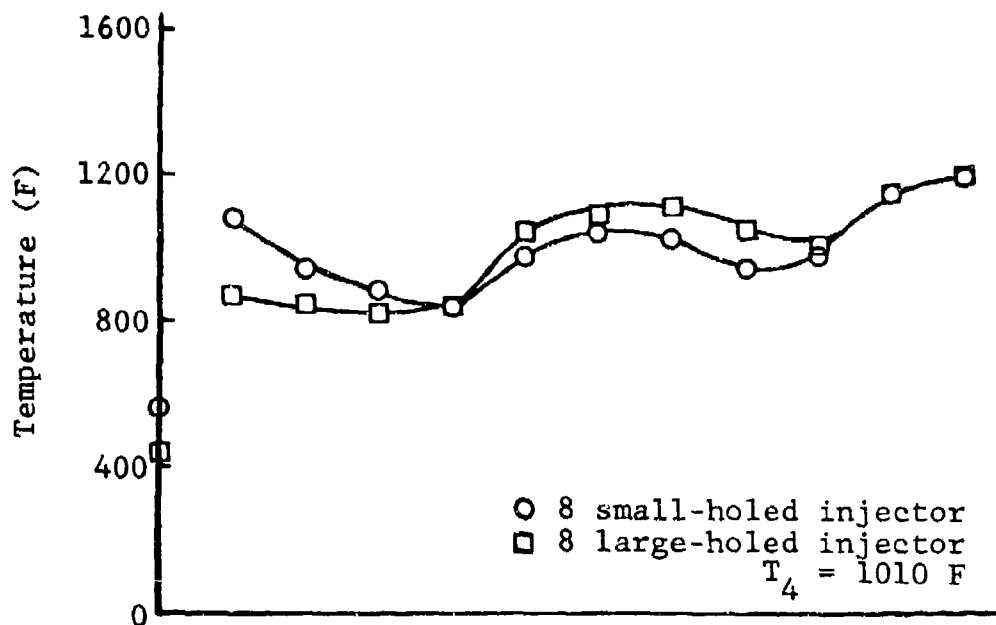


Fig 8A

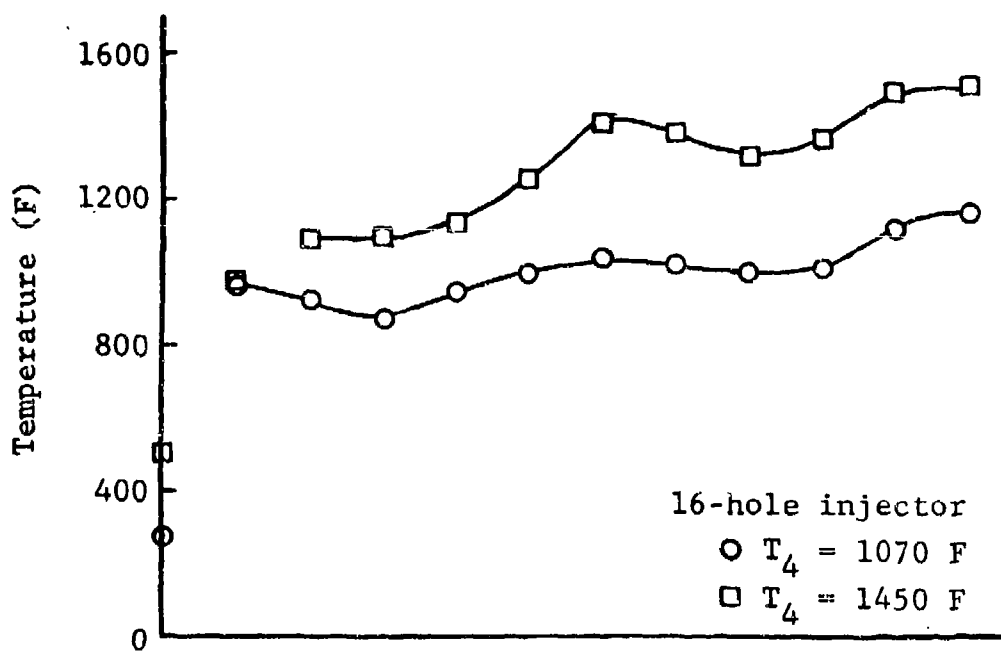


Fig 8B

Diametral Position

Figure 8. Catalyst Face Temperature Surveys

to the asymmetry of the combustor inlet/outlet configuration. The outlet pipe blocked part of the reverse flow inlet ducting , thus forcing more inlet air to the opposite side, which resulted in the temperature pattern. The first data point for each survey was neglected due to air entering around the thermocouple hole and giving erroneous readings near that side.

Turbine inlet temperature surveys were also performed for the 16 hole injector. The maximum variations were 55 F at an average turbine inlet temperature of 1045 F, and 190 F at an average of 1475. These temperature distributions were much better than those for the JP-4 fueled combustor, and well within an acceptable range.

Temperature Rise. The temperature rise across the combustor is the difference between the turbine and combustor inlet temperatures. This temperature rise was approximately linear with increases in fuel/air ratio (Fig 9). For each turbine housing/exhaust nozzle combination the temperature rise had a definite pattern, which was dependent on the mass flow. As a smaller nozzle was installed with a given turbine housing, the temperature rise curve shifted upward due to the decreased mass flow. A decreased mass flow allowed a longer residence time in the combustor, which provided more complete mixing and combustion.

For a given nozzle, a smaller turbine housing caused a higher engine speed and larger air input (at a given fuel/air ratio) and therefore a decreased combustor temperature rise (again due to the residence time within the combustor).

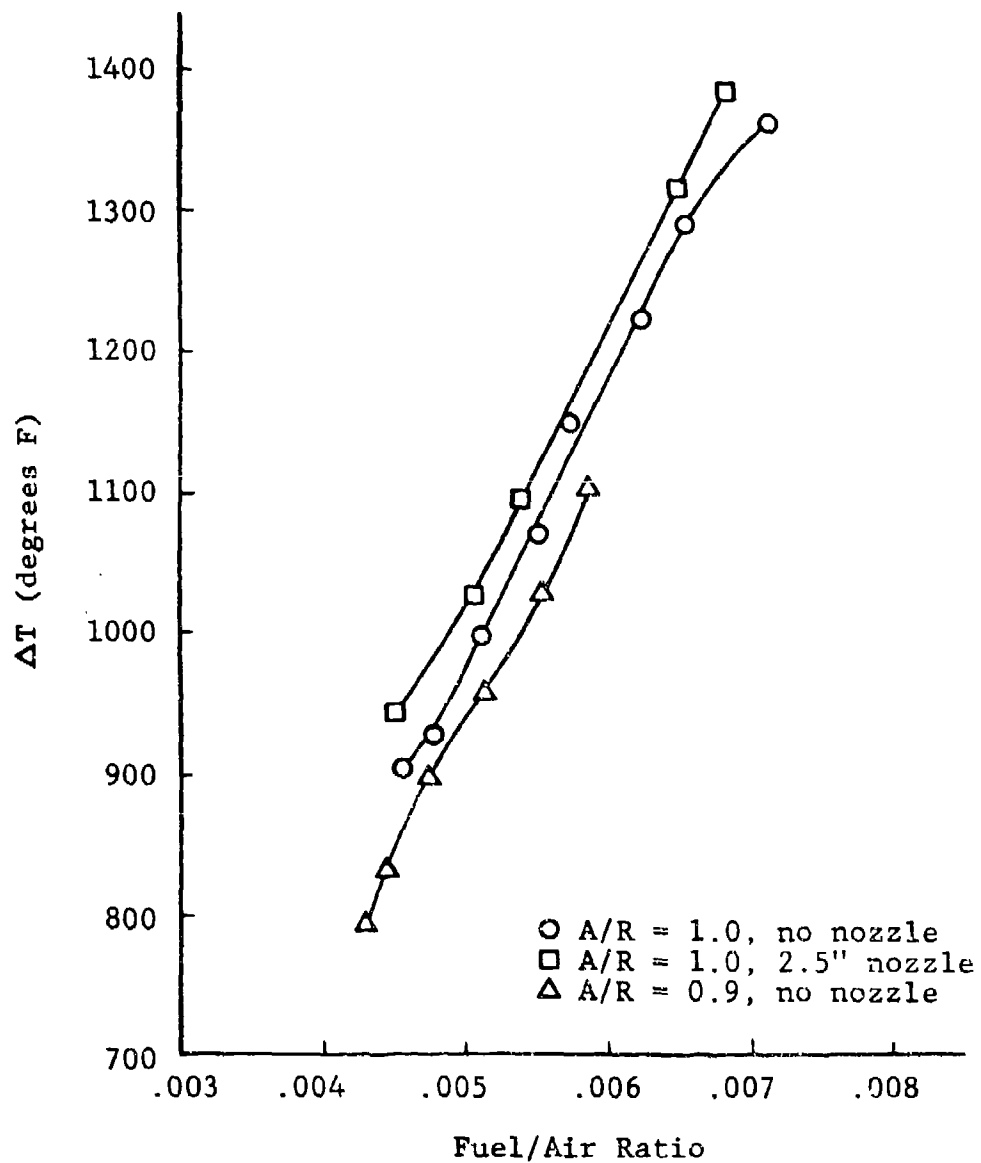


Figure 9. Combustor "B" Temperature Rise

The maximum combustor temperature rise (1565 F) was accomplished using the A/R = 1.0 turbine housing and 1.75 in. nozzle. The maximum combustor outlet temperature tested on the engine was 1855 F.

Total Pressure Loss. The total pressure loss for combustor "B" was very good. A cold flow bench test resulted in a 2.0% total pressure loss at a mass flow rate of 0.66 lbm/sec. The total pressure loss during heat addition ranged from 2% to 7% as shown in Fig 10. From Fig 10 and the cold flow bench test, the heat addition total pressure loss was approximately 4.5% at maximum combustor operating conditions. As mass flow increased the total pressure loss increased (linearly) due to the higher velocities within the combustor and greater heat addition losses. The scatter in the data was probably caused by recorder equipment variations during a test and data reduction errors.

Catalytic Element Damage. After testing was completed, combustor "B" was taken apart and the catalytic element was examined. Slight melting of the catalytic element had occurred on the combustor outlet pipe side, caused by the higher temperatures on that side as explained in the "Temperature Surveys" section, and due to the injector. One hole of the 16 hole injector was slightly larger than the others, causing slightly increased hydrogen flow on that side, and the "hot spot" was directly downstream of this hole.

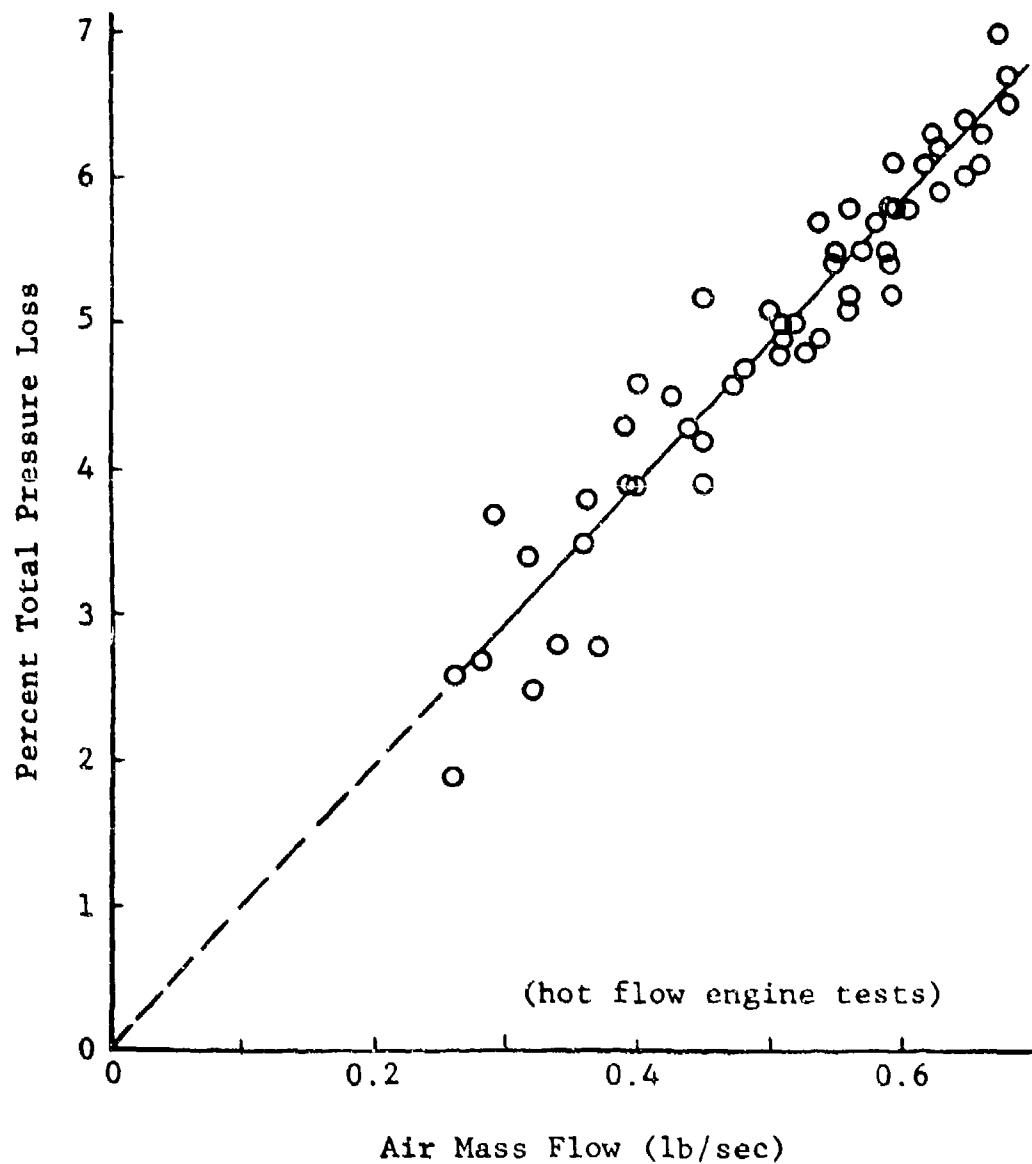


Figure 10. Combustor "B" Total Pressure Loss

V. Conclusions and Recommendations

As a result of the design and testing of combustors "A" and "B", the following conclusions and recommendations are made.

Conclusions

1. Combustor "B" proved successful on the turbocharger engine.
2. Total pressure losses in combustor "B" were less 7%, which was considered very good.
3. Turbine inlet temperature variations with combustor "B" were minimal and well within acceptable limits.
4. Upstream flame propagation in combustor "A" could not be prevented on the turbocharger engine.

Recommendations

In order to further determine the operation capabilities of the reverse flow catalytic combustor, the following ideas are recommended.

1. Study the use of commonly available gaseous fuels such as propane and acetylene, and liquid fuels such as gasoline and JP-4 in order to determine their suitability in the engine.
2. Obtain a catalytic element of silicon carbide with a high catalyst loading and cut it in thin wafers to determine the minimum catalytic element area necessary to begin combustion. Silicon carbide would be more likely to withstand the "hot spots" which slightly damaged the cordierite element.

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Appendix A

Instrumentation

The instrumentation signal processing and recording system was designed by Fisher (Ref 3). All engine parameter values except fuel flow were simultaneously recorded on a CEC Oscillograph Recorder. The recorded data consisted of temperature and total pressure measurements, engine speed (RPM), fuel pressure, engine thrust, and static pressure in the engine bellmouth inlet. Fuel flow was determined by using a 0.254 in. diameter orifice installed in the fuel line and measuring the differential pressure across the orifice. The differential pressure was measured on a water manometer located within the control room.

Air flow was determined on the external air supply test stand by measuring the differential pressure across a 1.8 in. diameter orifice with a mercury manometer. On the engine, three static pressure taps located on the bellmouth inlet measured inlet vacuum with a pressure transducer. Calibration curves developed by Greene (Ref 4: 31) and Kent (Ref 5: 62) were used to determine air mass flow.

Table 1 lists the number of temperature and total pressure probe measurements at different positions in the combustor. Chromel-alumel thermocouples were used in all cases except the combustor inlet, where an iron-constantan thermocouple was used. The thermocouples used in the temperature surveys were movable. Total pressure probes

were made of stainless steel and pressure was measured with pressure transducers.

Table 1
Combustor Instrumentation

| Position | Number of Thermocouples | Number of Pressure Probes |
|------------------|----------------------------|------------------------------|
| combustor inlet | 1 | 1 |
| catalyst face | 1 | 0 |
| combustor dome | 1 | 1 |
| combustor outlet | 2 | 1 |

Accuracy

According to Fisher (Ref 3), the maximum instrument error was less than 2.5%, with most errors in the 0.5 to 1.0 percent range. Therefore it is believed that the maximum error in the final reduced data is less than 4%, with the normal error within 3%.

A water manometer for fuel flow measurements was the only addition to Fisher's instrumentation system. Reduced data from these measurements are believed to have a maximum of 2.5% error.

Appendix B
Data Reduction

Data Collection

All measured engine parameters except fuel flow were recorded on light sensitive paper on a CEC Oscillograph Recorder. Each parameter had a calibrated displacement across the paper for a given parameter value. Table 1 lists the parameter, the channel on which it was recorded, and the appropriate scale factor. Therefore, to obtain direct, uncorrected data, measurements were taken on the light sensitive paper to the nearest one-hundreth of an inch (the light sensitive paper had lines every one-tenth of an inch) and multiplied by its calibrated scale factor.

Table 2
Scale Factors for Recorded Data

| Channel | Parameter | Scale Factor |
|---------|----------------|------------------|
| 2 | P_{H_2} | 38.46 psig/inch |
| 6 | \dot{m}_{am} | 4 in. water/inch |
| 7 | P_3 | 28 psig/inch |
| 8 | P_d | 28 psig/inch |
| 9 | P_4 | 28 psig/inch |
| 10 | T_3 | 100 F/inch |
| 11 | T_4 | 400 F/inch |
| 12 | T_d | 400 F/inch |

Data Reduction Equations

The air flow rate through the engine was determined by using the bellmouth inlet curve for the Rajay engine which was developed by Kent (Ref 5). It was then corrected to sea level conditions by using

$$\dot{m}_a = \dot{m}_{am} \sqrt{\frac{T_a}{519}} \cdot \frac{29.92}{P_a}$$

Hydrogen fuel flow was determined by the following equation where all conversion factors needed to use the data in its corrected form (P_{H_2}) have been taken into account.

$$\dot{m}_{H_2} = 0.0025428 \left(\frac{1 - 0.023268 \cdot h}{P_{H_2}} \right) \sqrt{\frac{P_{H_2} \cdot h}{T_{H_2}}}$$

The measured pressures were corrected by adding the ambient pressure.

$$P_c = P_g + P_a$$

Percent total pressure loss was determined by

$$P_{loss} = \frac{P_3 - P_4}{P_3} \cdot 100$$

Vita

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A catalytic combustor was designed, an existing one modified, and both were tested on a small turbojet engine. The turbojet engine was derived from an automotive turbocharger for use on remotely piloted vehicles. The existing catalytic combustor, combustor "A", used straight through flow and was modified by adding a flame arrestor to the combustor inlet. Combustor "B" was designed to use reverse flow with a preburner and air dilution zones. | | |

Combustors "A" and "B" were designed for an air capacity up to 0.75 lbm/sec and outlet temperatures of 1800 F. Combustor "B" did prove successful. Cold flow total pressure loss in combustor "B" was two percent, while the total pressure loss during heat addition was a maximum of seven percent. The flame arrestors tested on combustor "A" did not prove to be successful. Hydrogen was used as fuel for both combustors.

Temperature surveys were performed on combustor "B" in front of the catalytic element and at the turbine inlet. Temperatures across the catalyst face varied by 290 F at a turbine inlet temperature of 1070 F, 370 F at 1450 F. Turbine inlet temperatures varied by 55 F at an average 1045 F, 190 F at an average 1475 F. The maximum temperature rise across the combustor during testing was 1565 F and the maximum turbine inlet temperature tested was 1855 F.

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